

**TITLE:**

Investigation of Welded Studs on Overhead Sign Structures

**RESEARCH PERIOD:**

February – June 2006

**STATUS:**

Complete

**ABSTRACT:**

On September 28, 2005 a multi-disciplinary team composed of NCDOT and FHWA employees reviewed eight overhead signs in Division 5. The signs selected were known to have stud failures. The discovery of these stud failures necessitated investigation to determine if stud failures are a common problem throughout the state of North Carolina.

The overhead stud failure data was collected at randomly chosen overhead structures in all 14 Divisions. The North Carolina *Standard Specifications for Roads and Structures*, Section 1092-1 Signs and Hardware, utilizes more than 10% stud failure as evidence for rejection of the welding throughout the sign. With regard to this specification, 10% is used to determine stud failure.

This report summarizes and analyzes the inspection of 152 signs on 90 structures. The percentages of missing studs are shown in Table A, in relation to the total number of signs in each category.

TABLE A

Failure Rate	0 – 1 %	1 – 5 %	5 – 10 %	10 % +
Signs	118*	19	10	5

\*85 signs had no missing studs.

**CONCLUSIONS AND RECOMMENDATIONS:**

- The collected data demonstrates that welded aluminum stud failure is an isolated occurrence and not a persistent problem.
- Only five signs, or 3.3% of inspected signs, did not meet the specifications for new signs.
- Low number of signs not meeting specifications makes it impossible to determine cause of problem.
- We recommend that the studs undergo a visual inspection during the overhead inspection performed by the Bridge Maintenance Unit.
- We recommend implementing individual panel thru-bolt design in new signs.

## **I. INTRODUCTION**

A National Bridge Inspection Standards Review conducted on December 1<sup>st</sup> & 2<sup>nd</sup> 2004 noted a sign on bridge 204 over US 64 in Wake County as having stud failure. In the same month on the 23<sup>rd</sup> an overhead sign fell in Buncombe County striking a pick up truck. On September 28, 2005, the FHWA-NCDOT Overhead Sign Review found two signs that had suffered extensive stud failure and required immediate attention.

In response to these developments, the NCDOT Traffic Engineering Branch commissioned a survey of a random selection of 100 overhead sign structures. Of these 100 locations, 90 structures provided information useful to the issue at hand. This study will provide a sample of the extent of statewide stud failure and recommend action to prevent future problems.

## **II. SITE IDENTIFICATION - RANDOM LOCATIONS**

NCDOT Bridge Maintenance routinely inspects the structures of all overhead signs. Cantilevers are inspected every four years, and spans are inspected every eight years. They utilize an access database to track their inspections. The database contains extensive records on almost 1500 structure locations.

This list was used to select the 100 structures for inspection. First an attempt was made to filter all DMS and electronic signs. Then a random number generator was applied to chose 100 locations. From these 100 randomized locations, 90 structures were used in our findings. One structure had been removed. One structure had the cantilever arm removed. Three electronic signs passed through the filter or were not recorded as electronic in the original database. Five structures utilized the T-clip design. The randomization process chose locations in all 14 divisions, though some divisions are represented by a single overhead structure.

## **III. INSPECTION PROCESS**

The field inspection process was designed to obtain the number of stud failures on a sign. The size of the sign and the number of studs were estimated in the field. The number of missing studs, Z-Bars, and splice plates was visually counted. The presence of thru-bolts, overlaid signs, lights, and walkways was recorded. The sign face was photographed. The back of the sign was photographed with a 12x optical zoom to obtain high quality pictures for further review. The entire process of inspection typically took less than 30 minutes per structure. If there was an issue at the structure, the time could vary. It could take longer if inspection was difficult, or much less time if inspection was physically impossible. Structure chords interfering with Z-bar visibility were anticipated as a common problem.

### **A. Estimates**

#### **1. Sign Size**

To estimate the sign size, we used the splice lines on the face of the sign. Signs are fabricated from a 144"x 48" sheet of aluminum. Overhead signs require 16" or larger letters and almost never fit onto a single aluminum sheet. Aluminum sheets are spliced to produce the bigger signs. As the Roadway Standard Drawings call for vertical splices

with horizontal Z-bars, a splice represents 4' of width. The last sheet is estimated in comparison to the other sheets to obtain a horizontal width.

The vertical height is estimated through the number of Z-bars. The Roadway Standard Drawings call for the number of Z-bars based on the height of the sign. Signs shorter than 7' can be erected on two Z-bars. Signs taller than 12' need four to six Z-bars, and will have a horizontal splice. Most signs have three Z-bars, and fall between seven and twelve feet high. The width of the sign and the aluminum sheets also help to estimate the height.

## **2. Stud Count**

To obtain the estimated number of studs, two individuals produced a count. Since each vertical splice and Z-bar should be the same, only one of each required counting. The vertical splice and Z-bar counts were multiplied to get the total number. This was found to be faster and more accurate than counting each individual stud. The counts were typically within a few studs, but if large differences occurred, the studs were recounted.

## **B. Inspection Problems**

### **1. Blocked Visibility**

There were nine signs on six structures with significant areas that could not be inspected without a truck or climbing the structure. Typically the chords of the structure arm would obscure the Z-bar. In these cases, no missing studs could be counted, but we noted the area that was blocked from view.

### **2. T-Clips**

The second problem for stud inspection was the T-clip design (See Figure 1). Although this design was replaced over 20 years ago, nine T-clip signs on five structures fell into our survey. The T-clip design uses a T-shape section on the back of the sign. Although a count of the studs can be obtained from the bolts that go through the web of the T-shape, it is impossible to determine if the studs are intact from the ground.



**Figure 1 - T-clip Attachment Method**

## IV. SUMMARY OF DATA

### A. Summary

One hundred structure locations were visited. Five structures could not be included because they did not have signs with aluminum studs. Five structures utilized the T-clip attachment method. The 90 remaining structures held 152 signs. Of these 152 signs, 11 signs on six structures had partial inspection problems. Altogether, five signs on three structures definitely exceeded the 10% stud failure rate specified for new signs. Nine signs on five structures could surpass the 10% if the uninspectable area were to be missing several studs.

**TABLE B**

Number of Structures	Failure Percentage
3	>10%
7	5-10%
16	1-5%
64	<1%

### B. Structures with No Aluminum Stud Signs

Five structures had no signs with aluminum studs. Two of these structures were DMS locations. One structure used electronic signs for lane assignment. One structure had no cantilever arm. Another structure had either been removed altogether or suffered a location typo in the database.

### C. T-clip Signs

Of these remaining 95, five structures with nine signs utilized the T-Clip attachment method. The T-Clip attachment cannot be inspected from the ground.

### D. Blocked Visibility

Eleven signs on six structures were difficult to totally inspect from the ground. Structures 400650 and 640066 had signs whose visible stud count pushed them close to 10%, but not over. The areas that could not be inspected may have left these signs as not meeting specifications. Both of these structures will be discussed in greater detail below.

### E. Contractors

North Carolina generally contracts with 5-10 construction companies, skilled at installing overhead sign structures. Due to the low number of failures, there was no clear disparity between the installing contractors.

### F. Failures

Ten percent is used as a guideline for failure, as that is the limit on stud failure for new signs in the Standard Specifications for Roads and Structures. Using 10%, five signs on three structures need attention leaving 87 structures meeting the specification as new signs. However, raising the failure limit to 15% results in only structure 270057 having failures. One sign on this structure has been thru-bolted. Another sign could use attention, but the third sign only had one stud missing.

### G. Acceptable Signs

Out of the 90 structures, 87 structures have signs that meet the specification as new signs. This includes several signs that were erected in the 1980s. It is difficult to establish a cause for failures, since so few signs failed, and there is no apparent link between all of the signs.

### V. Structure and Sign Details

This section of the report will detail the results of the inspection of the ten structures with the highest failure percentages. Pictures of the worst areas on these signs are included.

County	Dare		
Division	1		
Route	US 158 WBL		
Structure Type	Span		
AADT	14,000		
# 2770057	Sign 1	Sign 2	Sign 3
Size	12'x5'	13'x10'	15'x12'
Z-bars	2	3	3
Total Studs	105	228	264
Missing Studs	88	73	1
% Missing	83.8	32.0	0.4
Thru-bolts	Yes	Yes	Yes
Fab/Erect Date	1999	1999	2003



Figure 2 - Sign Structure 270057

Unquestionably, the worst structure visited was 270057 in Dare County (Figure 2). This full span had suffered heavy stud failures. Although the largest sign had only one stud missing, it had been replaced in 2003. The small “REST AREA” sign (Sign 1) had lost over 80% of its studs. Division forces thoroughly thru-bolted each panel of the sign. The middle sign (Sign 2) had 32% stud failure with only the standard thru-bolts and the ends of the Z-bar (Figures 4 - 6).



Figure 3 - Sign 1 Thru-Bolts



**Figure 4 - Sign 2 Bottom Z bar**



**Figure 5 - Sign 2 Top Z bar**



**Figure 6 - Sign 2 Top Z bar**





**Figure 7 - Sign 1 Top Z bar**



**Figure 8 - Sign 1 Bottom Z bar**



**Figure 9 - Sign 1 Bottom Z bar**

County	Guilford
Division	7
Route	I-40 / I-85 EBL
Structure Type	Span
AADT	40,500
# <b>400656</b>	Sign 4
Size	26'x7'
Z-bars	3
Total Studs	288
Missing Studs	35
% Missing	12.2
Thru-bolts	Yes
Fab/Erect Date	1992



**Figure 10 - Sign Structure 400656**

This single sign span in Guilford County (Figure 10) experienced the second highest stud failure rate at 12.2%. This exceeds the new sign specification of 10%. There were blocked visibility issues on the top Z-bar, and the failure rate may be slightly higher than 12%.



**Figure 11 - Sign 4 Bottom Z bar**



**Figure 12 - Sign 4 Bottom Z bar**



County	Mecklenburg	
Division	10	
Route	US-74 WBL	
Structure Type	Span	
AADT	24,750	
# 590491	Sign 5	Sign 6
Size	18'x7'	18'x7'
Z-bars	2	2
Total Studs	226	226
Missing Studs	23	25
% Missing	10.2	11.1
Thru-bolts	No	No
Fab/Erect Date	None	None



**Figure 13 - Sign Structure 590491**

This structure holds Sign 5 and 6 in Mecklenburg County (Figure 13). Both signs just exceed the 10% failure criteria at 10.2% and 11.0%. The absence of thru-bolts dates the signs to 1992 at the latest. The structure was recorded as erected in 1985. The signs may be that old as well. The failures on this sign are primarily in the top Z-bars, as pictured.



**Figure 14 - Sign 6 Top Z bar**



**Figure 15 - Sign 5 Top Z bar**



**Figure 16 - Sign 5 Top Z bar**

County	New Hanover		
Division	3		
Route	US 421, 17, 74, 76		
Structure Type	Span		
AADT	23,000		
# 640066	Sign 7	Sign 8	Sign 9
Size	10'x10'	15'x8'	12.5'x11'
Z-bars	3	2	3
Total Studs	136	153	207
Missing Studs	11	13	18
% Missing	8.1	8.5	8.7
Thru-bolts	No	No	No
Fab/Erect Date	1988	1988	1988



**Figure 17 - Sign Structure 640066**

None of the signs on the structure (Figure 17) could be confirmed to exceed 10% from the ground. All three signs exceeded 8% failure and had bottom Z-bars that could not be inspected. Sign 8 had both of its Z-bars completely obscured, eliminating 40% of the studs from the inspection. Although no Z-bar failures were recorded and it is possible that none of the obscured areas were missing any studs and, it is more likely that at least 1 of the signs exceed the 10% failure rate. Only three additional missing studs on any of the signs result in exceeding the failure rate.



**Figure 18 – Obscured Z bars**



**Figure 19 - Sign 7 Obscured Z bar**



**Figure 20 - Sign 9 Splice Plate**

County	Wake
Division	5
Route	I-40 WBL
Structure Type	Cantilever
AADT	61500
# 910896	Sign 10
Size	21'x9'
Z-bars	3
Total Studs	310
Missing Studs	25
% Missing	8.1
Thru-bolts	No
Fab/Erect Date	1989



**Figure 21 - Sign Structure 910896**

This sign does not have thru-bolts and was erected in 1989 (Figure 21). The majority of the failures occurred in the middle and bottom Z-bar, creating a potential peeling problem. The sign is approaching the 10% failure rate, and if peeling is causing the localized stud failure, heavy wind loads could increase the sign failures.



**Figure 22 – Sign 10 Middle Z bar**



**Figure 23 – Sign 10 Bottom Z bar**



County	Guilford
Division	7
Route	I-40 / I-85
Structure Type	Span
AADT	40500
# 400650	Sign 11
Size	29'x6'
Z-bars	2
Total Studs	356
Missing Studs	23
% Missing	6.5
Thru-bolts	Yes
Fab/Erect Date	1992



**Figure 24 - Sign Structure 400650**

This structure (Figure 24) is missing 6.5% of its visible studs, but the top Z-bar was blocked from view by the structure itself. It is possible that the sign exceeds the 10% failure rate, but it is unlikely. The bottom Z-bar was missing eight studs. If the top mirrors the bottom, the sign would only approach 9% failure. Since the majority of the failures occurred in the splice plate, it would be unlikely for the top bar to have suffered heavier failures. The bottom bar failures were localized though, and this could result in the sign peeling from the failure area (See Figure 25).



**Figure 25 – Sign 11 Bottom Z bar**

County	Johnston
Division	4
Route	US-70 EBL
Structure Type	Cantilever
AADT	48,500
# <b>500570</b>	Sign 12
Size	20.5'x12'
Z-bars	3
Total Studs	254
Missing Studs	20
% Missing	7.9
Thru-bolts	No
Fab/Erect Date	None



**Figure 26 - Sign Structure 500570**

This structure (Figure 26) had 17 of 20 failures in the splice plates. The Z-bar studs were generally intact. The sign does not have thru-bolts, indicating a pre-1992 erection. Figure 27 shows three of the splice plate failures. Notice the failure underneath the Z-bar. The failures were not localized, as this picture indicates the tightest grouping of failures found on the sign.



**Figure 27 – Sign 12 Splice Plate**



County	Forsyth	
Division	9	
Route	I-40	
Structure Type	Span	
AADT	48,500	
# 330328	Sign 13	Sign 14
Size	21'x12'	18'x9'
Z-bars	3	3
Total Studs	298	250
Missing Studs	1	16
% Missing	0.3	6.0
Thru-bolts	Yes	No
Fab/Erect Date	2000	1990



**Figure 28 - Sign Structure 330328**

This structure is located in Forsyth County (Figure 28). Sign 14 was fabricated in 1990, so it does not have through bolts. The stud failures occur in the top and bottom Z-bar and in the splice plates. The failures are generally spread out and are not localized into one region. Figures 29 and 30 are the stud failures with the tightest grouping. Sign 13 was replaced in the year 2000.



**Figure 29 – Sign 14 Top Z bar**



**Figure 30 – Sign 14 Bottom Z bar**

County	Mecklenburg	
Division	10	
Route	I-277	
Structure Type	Span	
AADT	41,000	
# 590490	Sign 15	Sign 16
Size	15'x10.5'	17.5'x10'
Z-bars	3	3
Total Studs	225	269
Missing Studs	12	16
% Missing	5.3	5.9
Thru-bolts	No	No
Fab/Erect Date	None	None

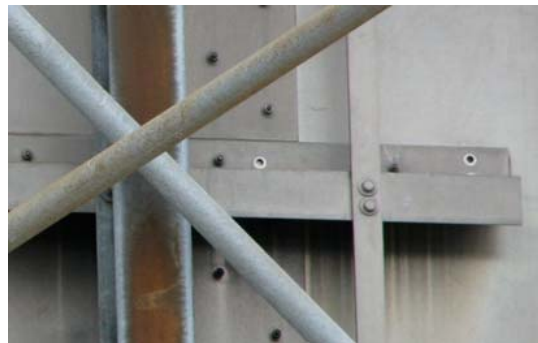


**Figure 31 – Sign Structure 590490**

These signs are not thru-bolted and do not have dates (Figure 31). The absence of thru-bolts indicates that the latest possible fabrication year would be 1992. The failures are primarily in the Z-bars, but they are not localized. Figures 32-35 display the stud failure groupings from the two signs.



**Figure 32 – Sign 15 Middle Z bar**



**Figure 33 – Sign 16 Middle Z bar**



**Figure 30 – Sign 14 Bottom Z bar**



**Figure 35 – Sign 15 Middle Z bar**

County	New Hanover	
Division	3	
Route	US 421	
Structure Type	Cantilever	
AADT	11,500	
# 640077	Sign 17	Sign 18
Size	9'x7'	7'x4'
Z-bars	2	2
Total Studs	105	55
Missing Studs	0	3
% Missing	0.0	5.5
Thru-bolts	Yes	Yes
Fab/Erect Date	1992	1992



**Figure 36 – Sign Structure 640077**

This structure is located in New Hanover County (Figure 36), where there are stronger winds. The stud failures are small in number. However, in this case it is likely that the missing studs are more of an anomaly than a potential problem. Also, the failures are in the splice plate, and are not providing structural support to the sign.

### **Detail Summary**

Although these 10 structures have the worst stud failures, over half of these locations would actually meet the specification for new sign fabrication. Of the five signs not meeting the new sign specification, three are only slightly above the allowed failure rate. One has been thru-bolted. In total, one sign out of the 152 inspected significantly exceeded the failure rate for new signs without countermeasures already in place. One hundred and ten out of 152 signs had one or no stud failures.

## **VI. CONCLUSIONS**

In general, the construction of overhead signs using ¼” welded studs is adequate. The inspections identified few locations needing further evaluation.

There are concerns regarding welded stud connections. The stud typically fails in the weld, as welded aluminum connections are often weaker than the surrounding material. In a March 21, 2006 memorandum, the Structure Design Unit approximates that a stud failed under a loading of approximately 24% of design strength. This indicates that stud failure occurs in irregular circumstances and cannot be predicted.

However, the collected data confirms that extensive stud failure is not a persistent problem.

The collected data shows welded studs perform as an adequate connection system. They provide a blemish free sign face, and they are reliable over time. However, there are cases where a combination of forces or poor weld performance may cause significant stud failure. These cases must be addressed to insure the safety of the public.

## **VII. RECOMMENDATIONS**

The collected data led to the conclusion that the welded stud system is typically adequate for North Carolina loading. However the isolated problems with stud failure cannot be ignored. Three simple countermeasures should address these isolated problems.

### **A. Visual Inspection**

A quick visual inspection of the stud connection could prevent significant stud failure from developing. The Bridge Maintenance Unit could perform a quick check for the presence of thru-bolts in the corners, a T-clip connection, and a count of missing studs. If the inspectors determine that 15% of the studs are missing or if there is an area of localized stud failure, they should contact the Traffic Engineering to further analyze the sign's connection and make a recommendation. If the sign has inspection difficulties, those areas should be addressed as failing.

The visual check would be very quick. Most overhead signs have only a few missing studs out of hundreds. Signs that have larger numbers of lost studs could be quickly estimated to determine if further evaluation is needed.

The data from these inspections could be used to track the locations and history of stud failures. This may help determine the cause and allow modifications to be made to prevent future weld failures.

### **B. Thru-bolts**

Thru-bolts can provide a backup or primary method of supporting the sign. Currently, thru-bolts are installed on the four corners of the sign and are intentionally loose up to an eighth of an inch with a self locking nylon insert nut. This prevents any compression on the sheeting, which avoids any dead cells and black rings in the thru bolt area of attachment.

When stud welds require attention, the simplest solution is to thru-bolt each panel of the sign. Although this increases the chance of damaging the sheeting, and has a tiny visual impact to the face of the sign, this is a cost-effective alternative to replacing the entire sign.

If a routine inspection cannot be implemented, we recommend thru-bolting each panel of all signs in areas with higher design windspeeds. The AASHTO Standard Specification for Structural Supports for Highway Signs, Luminaires, and Traffic Signals recognizes higher winds in the Coastal and Mountain regions of the states. These areas demonstrated a higher percentage of stud problems. These coastal divisions and mountain counties in question represent approximately 120 structures. The estimated average cost for labor, equipment, materials, and traffic control is \$800 per structure. However, if truck mounted impact attenuators or other expensive traffic control materials must be purchased, the cost could increase by tens of thousands. The total cost



of upgrading these signs approaches \$100,000. The bulk of the structures are in Divisions 2 and 3. Both have more than 40 structures to address. If each division were able to address 10 structures a year, in the year 2012, all overhead signs in these areas would be thru-bolted.

For new signs, we have asked the Structure Design Unit to create a new thru-bolt pattern to insure each panel is addressed. They currently anticipate using 2 bolts per panel for new signs. Figure 37 is a modified photograph that demonstrates the visual impact of the anticipated design on the sign face.



**Figure 37 – Rendering of Thru-Bolted Sign Face**

### **C. Sign Replacement**

If a routine inspection cannot be implemented, we recommend that the T-clip design be replaced. This connection has not been utilized for new signs in over 20 years. The Asheville sign that fell utilized this connection design. The connection tends to use less studs per bar, and the welds are older. Many of the signs have been overlayed, increasing the weight and sometimes the wind area of the signs. We estimate that 50 to 100 structures may still utilize the T-clip design. The signage on an overhead structure is estimated to cost around \$6000 per structure, with \$1200 for the disposal of the old sign and the erection of the new one. The total cost could approach \$1,000,000 depending on the final number of T-clip signs and whether the traffic control expenses can be mitigated. The timeline for this expense should be extended, so that many of these signs would be replaced for other reasons.